FRAME IDENTIFIER

Field of the Invention

This invention relates to discrimination between different communication signal frames, using pseudo-noise signals to determine which frame is present.

Background of the Invention

In certain communication systems that rely upon use of pseudo-noise techniques for signal discrimination, signals are transmitted within each of a sequence of frames, with each frame including a pseudo-noise preamble or post-amble section of a selected length L1 (expressed in bits or symbols) and a data section of length L2. Where the length L1 of the pseudo-noise preamble is greater than the number N1 of distinguishable pseudo-noise signals (each of original length N1), these pseudo-noise signals must be extended to a length L1, in some manner, in order to fill in the remaining bit or symbol spaces.

What is needed is an approach that provides an identification of frame number using a computable value associated with a pseudo-noise signal associated with a preamble (or post-amble) of the frame. Preferably, this approach should provide a unique correspondence between a computable value and a frame id.

Summary of the Invention

These needs are met by the invention, which provides a method and system for determining which frame is present by: (1) receiving two or more consecutive frames and computing overlap functions, OF(m;1) and OF(m;2) (e.g., correlation functions), for each of the frame preambles or post-ambles with a reference signal, where m is an offset index or integer; (2) determining the location ("phase") of the maximum amplitude of OF(m;k) ($k = 1, 2$) as the index m is varied; (3) forming a pth-order difference of the phases ($p \geq 1$); and (4) using the pth-order phase difference to determine a (unique) frame number that corresponds to the pth-order difference. The pth order difference can be defined in several ways to provide a unique correspondence with frame number.

Brief Description of the Drawings

Figure 1 illustrates a sequence of N1 consecutive frames used in the invention

Figure 2 illustrates two major components of a frame, with component lengths L1 and M1, processed by the invention.

Figure 3 is a graphical view of an correlation or overlap function computed from a basic pseudo-noise signal used in the invention.

Figures 4A, 4B and 4C are graphical views of correlation function maxima computed using different index values.

Figure 5 graphically illustrates how overlap functions for two consecutive frame preambles would appear.

Description of Best Modes of the Invention

A communication signal, as received and analyzed according to the invention, includes a sequence of N1 consecutive frames f_n, numbered n = 0, 1, 2, ... , N1-2, N1-1, with frame numbers being repeated periodically where required, as shown in Figure 1. Each frame f_n includes a pseudo-noise preamble or post-amble PN(t;n) (referred to collectively as a "designated pre-amble" herein) of length N1 bits or symbols ("units"), followed by or preceded by an OFDM sequence OFDM(t;n) that includes data that are being transmitted, as illustrated in Figure 2. In one embodiment of the invention, discussed here as an example, N1 = 253, N1' (= min value ≥ N1 of form 2^p-1) = 255, L1 = 378 and M1 = 3780.

In one embodiment of the invention, each pseudo-noise preamble PN(t;n) consists of a sequence of values (+1 or -1) and is optionally a time shifted replica of any other pseudo-noise preamble PN(t;n') in the ensemble of pseudo-noise signals of length N1; each augmented preamble is periodic:

$$PN(t;n) = PN(t + \Delta t(n;m);m), \tag{1}$$

Here the time shift value $\Delta t(n;m)$ is a selected number of units that may depend upon the indices m and n. More generally, PN(t;n) need not be a time-shifted

replica of PN(t;m), and the relationship is more complex. An overlap function, such as a correlation function,

$$C(n;m) = \int PN(t;n)\, PN(t;n+m)\, dt \quad (m = 0, \pm 1, \pm 2, \ldots), \tag{2}$$

computed over a selected interval for any pair of pseudo-noise signals, PN(t;n) and P(t;n+m), behaves approximately as illustrated in Figure 3: (1) small negative (or positive values) of C(n,m), except within a small band of indices m given by $m_{c1} \leq m \leq m_{c2}$; (2) C(n,m) rising monotonically, but not necessarily linearly, to a sharply defined peak as m increases to a central value, $m \rightarrow m_c$; (3) C(n,m) decreasing monotonically, but not necessarily linearly, to small negative (or positive) values as m increases beyond m_c, with $m \rightarrow m_{c2}$, with $m_{c1} < m_c < m_{c2}$. Optionally, the correlation function C(n;m) is periodic in the index m, with period equal to N1 or related to N1.

Because the number N1 (and thus length) of a PN signal used is less than the length L1 of the designated preamble, the quantity C(n;m) will have a main peak of amplitude C(max) and one or two subsidiary peaks of lesser amplitude, as indicated in Figures 4A, 4B and 4C. Except for effects of the presence of noise, one peak will always have an amplitude equal to C(max) and each of the other (subsidiary) peaks will have a reduced amplitude, no larger than C(max;sub) (< C(max)).

When two or more consecutive frames are received, the designated preamble PRE(t;m) for each frame is used to compute overlap functions

$$OF(m;k) = \int PRE(t;m)\, MS(t;k)\, dt \qquad (k = 1, 2, \ldots, N1') \tag{3}$$

over a discrete range, such as $-[(N1)/2]_{int} \leq m \leq [(N1+1)/2]_{int}$, over a corresponding continuous range, or over a selected sub-range for the N1 designated preamble signals, where MS(t;k) is a known m-sequence signal and k = 1, ... , N1 is an index that may represent a shift or translation of a single m-sequence, or {MS(t;k)} may be a collection of different m-sequences. If each of the designated preamble signals PRE(t;m) is a PN signal, each of the overlap functions will behave as illustrated in Figure 3, as a function of the unknown

frame index m, and each overlap function OF(m;k) will have a maximum peak value and a corresponding peak value location or phase, $m = m_c(k)$.

Figures 5 graphically illustrates how the overlap functions OF(m;k) would appear in a preferred embodiment in which the correlation function in Figure 3 is linear in the region $m_{c1} \le m \le m_{c2}$ for each such function. Each overlap function will manifest a main peak, of height approximately equal to C(max), and one or two subsidiary peaks of lesser amplitude with maximum peak value(s) C(max;sub) < C(max). Ideally, the main peak will have the value C(max), except for the presence of noise, where the main peak may have a reduced value, at least equal to C(max;red), with C(max;sub) < C(max;red) < C(max). Optionally, the system applies a threshold criterion and determines only the location of any main peak whose amplitude C(peak) satisfies

$$C(\text{peak}) > C_{thr} = w\cdot C(\text{max;sub}) + (1-w)\cdot C(\text{max;red}), \tag{4}$$

where w is a selected real number satisfying $0 \le w \le 1$. This optional approach again ensures that only the maximum peak amplitude, and its corresponding phase, will be identified.

Each of the locations, $m = m_c(1)$ and $m = m_c(2)$, of the maximum peaks for the overlap functions, OF(m;k) and OF(m+1;k), of two or more consecutive frames has an associated phase $\phi(m)$, an integer or other index that ranges from -63 to +63 and generally has two different frames (e.g., nos. 51 and 201, each with phase $\phi(m) = -26$) that correspond to the same phase. Table 1 sets forth phases and phase differences associated with each of the 253 frames. Thus, an individual phase $\phi(m)$ cannot be used as a unique identifier for the unknown frame number m. However, a first-order phase difference

$$\Delta_1(m) = \phi(m+1) - \phi(m) \tag{5}$$

also set forth in Table 1, varies from 0 to +126 and from -1 to -126 and is unique, if not monotonic, for each of the 253 frames.

Thus, $\Delta_1(m)$ can be computed and compared against a table or data base to determine the frame number m. If $\Delta_1(m)$ is negative, the frame number is odd

(e.g., 1, 3, 5, ... , 251); and if $\Delta_1(m)$ is positive, the frame number is even. The frame number itself can be determined from the following:

$$0 \leq \Delta_1(m) \leq 126 \text{ and even: } m = \Delta_1(m);$$
$$1 \leq \Delta_1(m) \leq 125 \text{ and odd: } m = 253 - \Delta_1(m);$$
$$-126 \leq \Delta_1(m) \leq -2 \text{ and even: } m = 253 + \Delta_1(m);$$
$$-125 \leq \Delta_1(m) \leq -1 \text{ and odd: } m = -\Delta_1(m). \qquad (6)$$

Equation (6) can be expressed here as an inverse mapping $m = F\{\Delta_1(m)\}$.

From Table 1, one verifies that the first-order phase sums satisfy

$$\Sigma_1(m) = \phi(m) + \phi(m+1) = \pm 1, \qquad (7)$$

and the values +1 and -1 should alternate as m increases. These constraints can be used to check for consistency in the phases $\phi(m)$, where $\phi(m)$ is allowed to have integer and non-integer values. For example, the peaks of three consecutive overlap functions, OF(m;k) and OF(m+1;k) and OF(m+2;k) (k = unknown frame no. = 1, 2, ...), may appear to occur at non-integer values m = m' and m = m'' and m = m''', such as $\phi(m') = 6.9$ and $\phi(m'') = -7.4$ and $\phi(m''') = 8.7$. As a first approach, one might re-assign the indices to nearest-integer values, $\phi(m') \rightarrow 7$, $\phi(m'') \rightarrow -7$ and $\phi(m''') \rightarrow 9$. However, the sums become

$$\Sigma_1(m) = \phi(m') + \phi(m'') = 0, \qquad (8A)$$
$$\Sigma_1(m) = \phi(m'') + \phi(m''') = +2, \qquad (8B)$$

each of which is clearly inconsistent with the constraints set forth in Eq. (10). One method of avoiding these inconsistencies is to (re)assign $\phi(m'') = -8$, whereby the sums become

$$\Sigma_1(m) = \phi(m') + \phi(m'') = -1, \qquad (9A)$$
$$\Sigma_1(m) = \phi(m'') + \phi(m''') = +1, \qquad (9B)$$

which is consistent with Eq. (10). If each of two consecutive sums, $\Sigma_1(m)$ and $\Sigma_1(m+1)$, does not satisfy the constraint in Eq. (7), adjustment of the reassigned phase value $\phi(m+1)$ may satisfy each of the corresponding constraints.

Other phase differences $\Delta_n(m)$ may or may not provide a unique correspondence with frame number. For example, the second-order phase difference

$$\Delta_2(m) = \Delta_1(m+1) - \Delta_1(m)$$
$$= \phi(m+2) - 2\phi(m+1) + \phi(m) \qquad (10)$$

does not provide a unique correspondence because, for example

$$\Delta_2(m=124) = \Delta_2(m=126) = 251. \qquad (11)$$

This is also true for the fourth-order phase difference

$$\Delta_4(m) = \phi(m+4) - 4\phi(m+3) + 6\phi(m+2) - 4\phi(m+1) + \phi(m), \qquad (12)$$

where, for example,

$$\Delta_4(m=122) = \Delta_4(m=126) = -988. \qquad (13)$$

However, the third order phase difference, defined by

$$\Delta_3(m) = \phi(m+3) - 3\phi(m+2) + 3\phi(m+1) - \phi(m), \qquad (14)$$

does provide a unique correspondence with frame number m. It is postulated here that a Qth-order phase difference ($Q \geq 2$), defined as

$$\Delta_Q(m) = \sum_{q=0}^{Q} (-)^q \{Q!/(Q-q)!\ q!\}\ \phi(m+q). \qquad (15)$$

does provides a unique correspondence with frame number (only) for odd integers Q. More generally, a suitably weighted linear combination, such as

$$LC(m) = \Delta_1(m) \pm 0.5 \cdot \Delta_2(m) \pm 0.25 \cdot \Delta_3(m) \pm 0.125 \cdot \Delta_4(m) \qquad (16)$$

can provide a unique correspondence, because the pair of indices at which $\Delta_2(m)$ is not unique and the pair of indices at which $\Delta_4(m)$ is not unique, do not coincide. More generally, a linear combination such as

$$LC(m) = \sum_{p=1}^{P} c(p)\ \Delta_p(m) \qquad (P \geq 2) \qquad (17)$$

may provide a unique correspondence, where at least one coefficient c(p) is non-zero. In particular, a linear combination LC(m) for which

$$c(1) = 1, \qquad (18A)$$
$$c(p+1)/c(p) \leq 0.5 \quad (p = 1, \ldots, P-1), \qquad (18B)$$

provides a unique correspondence.

Table 1. Frame Numbers; Phases; Phase Differences

FrameNo	Φai(m)	Delta1(m)	Delta2(m)	Delta3(m)	Detla4(m)
0	0	0	-1	4	-12
1	-1	-1	3	-8	20
2	1	2	-5	12	-28
3	-2	-3	7	-16	36
4	2	4	-9	20	-44
5	-3	-5	11	-24	52
6	3	6	-13	28	-60
7	-4	-7	15	-32	68
8	4	8	-17	36	-76
9	-5	-9	19	-40	84
10	5	10	-21	44	-92
11	-6	-11	23	-48	100
12	6	12	-25	52	-108
13	-7	-13	27	-56	116
14	7	14	-29	60	-124
15	-8	-15	31	-64	132
16	8	16	-33	68	-140
17	-9	-17	35	-72	148
18	9	18	-37	76	-156
19	-10	-19	39	-80	164
20	10	20	-41	84	-172
21	-11	-21	43	-88	180
22	11	22	-45	92	-188
23	-12	-23	47	-96	196
24	12	24	-49	100	-204
25	-13	-25	51	-104	212
26	13	26	-53	108	-220
27	-14	-27	55	-112	228
28	14	28	-57	116	-236
29	-15	-29	59	-120	244
30	15	30	-61	124	-252
31	-16	-31	63	-128	260
32	16	32	-65	132	-268
33	-17	-33	67	-136	276
34	17	34	-69	140	-284
35	-18	-35	71	-144	292
36	18	36	-73	148	-300
37	-19	-37	75	-152	308
38	19	38	-77	156	-316
39	-20	-39	79	-160	324
40	20	40	-81	164	-332
41	-21	-41	83	-168	340
42	21	42	-85	172	-348
43	-22	-43	87	-176	356
44	22	44	-89	180	-364
45	-23	-45	91	-184	372
46	23	46	-93	188	-380
47	-24	-47	95	-192	388
48	24	48	-97	196	-396
49	-25	-49	99	-200	404
50	25	50	-101	204	-412
51	-26	-51	103	-208	420
52	26	52	-105	212	-428
53	-27	-53	107	-216	436
54	27	54	-109	220	-444
55	-28	-55	111	-224	452
56	28	56	-113	228	-460
57	-29	-57	115	-232	468
58	29	58	-117	236	-476
59	-30	-59	119	-240	484
60	30	60	-121	244	-492
61	-31	-61	123	-248	500
62	31	62	-125	252	-508
63	-32	-63	127	-256	516
64	32	64	-129	260	-524
65	-33	-65	131	-264	532
66	33	66	-133	268	-540
67	-34	-67	135	-272	548
68	34	68	-137	276	-556
69	-35	-69	139	-280	564
70	35	70	-141	284	-572
71	-36	-71	143	-288	580
72	36	72	-145	292	-588
73	-37	-73	147	-296	596
74	37	74	-149	300	-604
75	-38	-75	151	-304	612
76	38	76	-153	308	-620
77	-39	-77	155	-312	628
78	39	78	-157	316	-636

Frame No.	$\phi(m)$	$\Delta_1(m)$	$\Delta_2(m)$	$\Delta_3(m)$	$\Delta_4(m)$
79	-40	-79	159	-320	644
80	40	80	-161	324	-652
81	-41	-81	163	-328	660
82	41	82	-165	332	-668
83	-42	-83	167	-336	676
84	42	84	-169	340	-684
85	-43	-85	171	-344	692
86	43	86	-173	348	-700
87	-44	-87	175	-352	708
88	44	88	-177	356	-716
89	-45	-89	179	-360	724
90	45	90	-181	364	-732
91	-46	-91	183	-368	740
92	46	92	-185	372	-748
93	-47	-93	187	-376	756
94	47	94	-189	380	-764
95	-48	-95	191	-384	772
96	48	96	-193	388	-780
97	-49	-97	195	-392	788
98	49	98	-197	396	-796
99	-50	-99	199	-400	804
100	50	100	-201	404	-812
101	-51	-101	203	-408	820
102	51	102	-205	412	-828
103	-52	-103	207	-416	836
104	52	104	-209	420	-844
105	-53	-105	211	-424	852
106	53	106	-213	428	-860
107	-54	-107	215	-432	868
108	54	108	-217	436	-876
109	-55	-109	219	-440	884
110	55	110	-221	444	-892
111	-56	-111	223	-448	900
112	56	112	-225	452	-908
113	-57	-113	227	-456	916
114	57	114	-229	460	-924
115	-58	-115	231	-464	932
116	58	116	-233	468	-940
117	-59	-117	235	-472	948
118	59	118	-237	476	-956
119	-60	-119	239	-480	964
120	60	120	-241	484	-972
121	-61	-121	243	-488	980
122	61	122	-245	492	-988
123	-62	-123	247	-496	996
124	62	124	-249	500	-1003
125	-63	-125	251	-503	1006
126	63	126	-252	503	-1003
127	-63	-126	251	-500	996
128	62	125	-249	496	-988
129	-62	-124	247	-492	980
130	61	123	-245	488	-972
131	-61	-122	243	-484	964
132	60	121	-241	480	-956
133	-60	-120	239	-476	948
134	59	119	-237	472	-940
135	-59	-118	235	-468	932
136	58	117	-233	464	-924
137	-58	-116	231	-460	916
138	57	115	-229	456	-908
139	-57	-114	227	-452	900
140	56	113	-225	448	-892
141	-56	-112	223	-444	884
142	55	111	-221	440	-876
143	-55	-110	219	-436	868
144	54	109	-217	432	-860
145	-54	-108	215	-428	852
146	53	107	-213	424	-844
147	-53	-106	211	-420	836
148	52	105	-209	416	-828
149	-52	-104	207	-412	820
150	51	103	-205	408	-812
151	-51	-102	203	-404	804
152	50	101	-201	400	-796
153	-50	-100	199	-396	788
154	49	99	-197	392	-780
155	-49	-98	195	-388	772
156	48	97	-193	384	-764
157	-48	-96	191	-380	756
158	47	95	-189	376	-748

Frame No.	Φ(m)	Δ_1(m)	Δ_2(m)	Δ_3(m)	Δ_4(m)
159	-47	-94	187	-372	740
160	46	93	-185	368	-732
161	-46	-92	183	-364	724
162	45	91	-181	360	-716
163	-45	-90	179	-356	708
164	44	89	-177	352	-700
165	-44	-88	175	-348	692
166	43	87	-173	344	-684
167	-43	-86	171	-340	676
168	42	85	-169	336	-668
169	-42	-84	167	-332	660
170	41	83	-165	328	-652
171	-41	-82	163	-324	644
172	40	81	-161	320	-636
173	-40	-80	159	-316	628
174	39	79	-157	312	-620
175	-39	-78	155	-308	612
176	38	77	-153	304	-604
177	-38	-76	151	-300	596
178	37	75	-149	296	-588
179	-37	-74	147	-292	580
180	36	73	-145	288	-572
181	-36	-72	143	-284	564
182	35	71	-141	280	-556
183	-35	-70	139	-276	548
184	34	69	-137	272	-540
185	-34	-68	135	-268	532
186	33	67	-133	264	-524
187	-33	-66	131	-260	516
188	32	65	-129	256	-508
189	-32	-64	127	-252	500
190	31	63	-125	248	-492
191	-31	-62	123	-244	484
192	30	61	-121	240	-476
193	-30	-60	119	-236	468
194	29	59	-117	232	-460
195	-29	-58	115	-228	452
196	28	57	-113	224	-444
197	-28	-56	111	-220	436
198	27	55	-109	216	-428
199	-27	-54	107	-212	420
200	26	53	-105	208	-412
201	-26	-52	103	-204	404
202	25	51	-101	200	-396
203	-25	-50	99	-196	388
204	24	49	-97	192	-380
205	-24	-48	95	-188	372
206	23	47	-93	184	-364
207	-23	-46	91	-180	356
208	22	45	-89	176	-348
209	-22	-44	87	-172	340
210	21	43	-85	168	-332
211	-21	-42	83	-164	324
212	20	41	-81	160	-316
213	-20	-40	79	-156	308
214	19	39	-77	152	-300
215	-19	-38	75	-148	292
216	18	37	-73	144	-284
217	-18	-36	71	-140	276
218	17	35	-69	136	-268
219	-17	-34	67	-132	260
220	16	33	-65	128	-252
221	-16	-32	63	-124	244
222	15	31	-61	120	-236
223	-15	-30	59	-116	228
224	14	29	-57	112	-220
225	-14	-28	55	-108	212
226	13	27	-53	104	-204
227	-13	-26	51	-100	196
228	12	25	-49	96	-188
229	-12	-24	47	-92	180
230	11	23	-45	88	-172
231	-11	-22	43	-84	164
232	10	21	-41	80	-156
233	-10	-20	39	-76	148
234	9	19	-37	72	-140
235	-9	-18	35	-68	132
236	8	17	-33	64	-124
237	-8	-16	31	-60	116
238	7	15	-29	56	-108

Frame No.	$\Phi(m)$	$\Delta_1(m)$	$\Delta_2(m)$	$\Delta_3(m)$	$\Delta_4(m)$
239	-7	-14	27	-52	100
240	6	13	-25	48	-92
241	-6	-12	23	-44	84
242	5	11	-21	40	-76
243	-5	-10	19	-36	68
244	4	9	-17	32	-60
245	-4	-8	15	-28	52
246	3	7	-13	24	-44
247	-3	-6	11	-20	36
248	2	5	-9	16	-28
249	-2	-4	7	-12	20
250	1	3	-5	8	-12
251	-1	-2	3	-4	4
252	0	1	-1	0	4